REDUCING THE OPERATIONAL STOP TIME OF HAULLER KOMATSU HD465-7 BY USING THE SIX SIGMA'S APPROACH IN PT X

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ABSTRACT

An operational stop time is a condition where heavy equipment is not working as usual. It is important to avoid this condition since excessive idling wastes an enormous amount of fuel and money. However, the operational stop time of a dump truck Hauller HD465-7 is 2.83 minutes, which is far above the normal standard. This project aims to optimize the improvement of an operational stop time by using a Six Sigma method with optimize plan selection. This will return the operational stop time to the standard range within 1.25 to 1.65 minutes. These steps of define, measure, analyze, improve, and control are applied to the standardization process according to the rules and criteria established by the Six Sigma. The result found that the Six Sigma's approach which was applied in PT X has reduced the cost from US$1,105,300 to US$963,000 every month. An improvement have been made to matching fleet by combining six fleet of dump trucks at driving speed of 22 km per hour and the average simulated haul distance was 2,000 meters.

Keywords: stop time, dump truck, six sigma, improvement

INTRODUCTION

Six Sigma is a business strategic management which originally developed by Motorola in 1986 in order to enhance the quality of products through decreasing of product variations on manufacturing operations as they face compete in semiconductor industries. Through the application of the Six Sigma method, Motorolla has acknowledged an award of Malcolm Baldrige in 1988 as the first American's company which won its prestigious quality's award (Parsana *et al.* 2014). Six Sigma consists of a set of process where 99.9996 percent of resulted products are statistically expected to be free defects (3.4 ppm of level of reject or defect). Recently, the success processing rate of 99 percent is no longer being reminded and the world-class companies continue to enhance to provide both services and products perfectly to address zero defects. The main idea of Six Sigma is an approach to design the processes or to improve existing process to gain a very high capability/ability process in favor of near zero defects (Kwak *et al.* 2006). To illustrate why obtained level of 99 percent of quality is no longer enough, some facts are considered (McClusky, 2000). First, on mail delivery, reaching the quality of 99 percent meaning there are 10,000 mails are lost in every hour. Second, landing at airports for the quality of 99 percent meaning there are two unsafe landed aircraft in every hour. Third, medical surgical for the quality of 99 percent meaning there are 500 patients undergoing surgical errors in every week. Fourth, power plant operations for the quality of 99 percents implies seven hours blackout within a month.

According to these facts, by considering an obtained quality level for only 99 percent or 1 percent of defect levels on such cases in manufacturing industries or services can potentially lead to fatalities. Hence, for gaining the target of quality level of 99.9996 percent or free-defects, an

organization requires both flexibility and discipline in solving problems using statistical approach rather than using simple intuition or by trial and error; wider usage of statistical treatments is one of the benefits of Six Sigma method (Pacheco, 2014). Application of Six Sigma's method is more valuable due to its contribution to the science and practice for particularly reduces waste and provides added values. Six Sigma allows users to identify waste and hidden costs, eliminates defects, increases profit margin, satisfies customers, encourages employee commitment and satisfaction as well as expands businesses (Patil *et al*, 2015).

The world-class companies within the Fortune 200's category such as Motorolla, GE, Bank of America, Honeywell, Boeing, Ford and other companies were using the Six Sigma programs to maximize their profits (Raisinghani, 2005 and Kabir *et al*, 2013). Six Sigma as a management system is applied to ensure that efforts and critical opportunities for improvement are well developed through metric methodology and an applied level is inline with its business strategy. Six Sigma enables an organization to improve quality process by identifying and eliminating the causes of defects and error terms through minimizing variability in manufacturing and business processes (Mittal, 2014). The stages for improve process ability (process capability) regarding Six Sigma method are specifically allowing the standar steps such as define, measure, analyze, improve, and control for interlinked statistical tests. For a particular project within organization of applied of Six Sigma the stage is typically consists of a step-by-step requires for obtain measurable target values i.e. reduces cycle time, decreases air pollution, reduces costs, improves customer satisfaction, and increases profits (Mittal, 2014). It is inevitable, in order to gain benefits, as a results of Six Sigma's application in an organization or company, would require relatively high of initial investment, but might be offer benefits in long terms including cost savings, generated profits, improved consistency of quality processes, better employee performance, and better service quality and products. Those elements particularly would lead an organization or company to provide a higher customer satisfaction as well as to gain the ultimate goal of organization (Mittal, 2014). The existence of Six Sigma can be seen as a philosophy, business strategy, repair tool, and statistical measurement. Six Sigma is generally a management strategy, culture and change, and the need for organization to build as a whole into company's strategy plan. Six Sigma activities are focused on reducing the level of defect/failure of product or process (Taneja & Manchanda, 2013).

It is inevitable for an initial investment for application of Six Sigma as a tool requires high costs and probably only big companies be able to do so. Thus, training is required to implement and the objective is for everyone in organization or company to understand and involve. Application of Six Sigma's method requires higher investment than the lean (Anthony, 2011). The basic trainings of Six Sigma (white belt level) for one day would cover mapping process and description of various experimental designs such as design of experiment, hypothesis testing, and modeling process. A green belt training level has broader scope and longer duration; generally would conduct a week, the scope consists of a study of statistical analysis, statistical usage related to controlling process, and measurement systems and analysis. A higher one is black belt's level might be achieved through a completely intensive training course during one month, learn more in-depth analysis of variance (ANOVA), multivariate regression, and game theory (Raisinghani, 2005). Goal of the series of training and examinations is to make engineers to cope the green belt and black belt levels, enable them to work on innovative projects using Six Sigma's rule and standard, though it takes time to implement and higher initial investment is needed. The challenge is particularly how to keep small companies with limited capital expenditures can also be viewed as an interface with implemented methods in order to encourage their performance (Mittal, 2014). Six Sigma'method is used to obtain factual information regarding customer satisfaction applying such steps, i.e. define measure, analyze, improve, and control (DMAIC). Six Sigma as a measurement standard is referred to the theory of Carl Friedrich Gauss (1777-1855) who initially introduced the concept of normal distribution. Furthermore, Walter Shewhart found three sigmas as a measurement of variation in 1922, which stated that the process and intervention are needed if output goes beyond a limit (Raisinghani, 2005). There are two circumstances faced by manufacturing companies in terms of level of quality or high quality during

1980's period in the United States. The first one is an introduction of mass production of miniaturized electronics, transistor from radio to television, etc., which produce in large quantities for mass-market consumption. Secondly most related to opening of the United States market to foreign products particularly electronic devices made in Japan, which is the driving force to increase the quality of domestic products that was made in America. Both the quality and feature of products are two of the most advantages that made Japanese products are highly attractive to global consomers including American market (Raisinghani, 2005).

In order to response to Japanese foreign market penetration, an effort has been taken to a certain number of policy measures to improve the quality in the 1980's period. As the results, Ford Motor's automotive company introduced the quality system of zero defects, Boeing and Bell Telephone applied the concept of total quality management, Honeywell electronics and Fairchild developed the quality cycle concept that allows the average employee to engage more seriously by finding out what its customers need and enabling employees to deliver customer-oriented promises successfully (Raisinghani, 2005). The Nation has also seen the significant importance of the products and services. The Malcolm Baldrige National Quality Award (MBNQA) was established in 1987 by the U.S. Congress in an effort to promote quality improvement initiatives in U.S. businesses. The award program was named after former Secretary of Commerce, Malcolm Baldrige, and was designed and managed by the National Institute of Standards and Technology (NIST) with the help of private companies. Baldrige National Quality Improvement Act of 1987 (Public Law 100-107) signed into The Baldrige National Quality Award Program that was created by Congress through the Malcolm law by President Reagan on August 20, 1987.

METHODS

The method used to reduce the operational stop time of operation of Hauller Komatsu HD 465-7 is done with the series of Six Sigma standard procedures: (1) Define: define problem is the first phase of the Six Sigma improvement project. The main activities of this phase are to identify customers' needs in identifying their measurable improvement programme. (2) Measurement: the measurement in DMAIC is about understanding the current process, how the process is measured, and its baseline refers to a data-driven improvement cycle used for improving. (3) Analyze: the analyze phase is the beginning of the statistical analysis of the problem. The practical problem was created earlier. This phase statistically reviews the families of variation to determine which variables are the most significant contributors to the output. The statistical analysis is done beginning with a theory, null hypothesis. The analysis will fail to reject or reject the theory. (4) Improvement: The goal of the DMAIC Improve phase is to identify a solution to the problem that the project aims to address. This involves brainstorming potential solutions, selection solutions to test and evaluating the results of the implemented solutions. Often a pilot implementation is conducted prior to a full-scale rollout of improvements. It is important to include the people who are involved in performing the process in the first stage of improvement. Their input regarding potential improvements is critical, and this step should not be completed by the project team alone. In fact, it is wise to maintain communication with those who work on the process throughout any Six Sigma quality improvement project. (5) Control: The control phase is the conclusion of the team's journey. The primary objective of the DMAIC control phase is to ensure that the gains obtained during improve are maintained long after the project has ended. To that end, it is necessary to standardize and document procedures, make sure all employees are trained and communicate the project's results. In addition, the project team needs to create a plan for ongoing monitoring of the process and for reacting to any problems that arise.

Define

The earth-moving dump truck vehicle consists of five steps (Figure 1): (1) Loaded stop time: the time it takes the loading equipment to load the dump truck. (2) Loaded drive time: the time to travel to the dump site. (3) Unloaded stop time: the time required to unload. (4) Operational drive time: the time to travel to the load site. (5) Operational stop time: the waste time in waiting between loads.

An operational stop (wait) conditions creates underutilized trucks and look for opportunities to reduce wait times using the Six Sigma tool. Truck wait time occurs when the truck must wait to be loaded or to dump because of nonsynchronization in the haulage system.

Figure 1 Process Flow Houling Activity

Operational stop times can be reduced by improving dump truck allocation and supervision and by dispatching systems. The average operational stop time of Komatsu HD 465-7 is 2.83 minutes, higher than 1.40 minutes meets the improvement target. The goals and targets examined here are those related to the cost quality and productivity (CQP) aspects with a breakthrough idea is to synchronize the improvement of a mixed fleet of Komatsu HD 465-7 and excavator Komatsu PC1250-7.

Measurement

As described above, operational stopped time is all the time that the truck was stopped during the entire haul cycle while it was operational. If the operational stopped time is high it would tend to suggest that there is a lot of time waiting at the loading tool. It could also reflect trucks left idling through breaks to keep the air conditioner or heater running. But the important point here is that it provides a clue as to where to look in the field if we want to reduce the idle time. If it turns out the operational stopped time is being incurred at the loading tool, we can then work out whether we are running too many trucks, whether the loading tool operator needs training, etc. Figure 2 shows the operational stopped times for Hauler Komatsu HD 465-7 based on actual field measurements. The Total Gage R&R contribution in the % Study Var column (% Tolerance, % Process) is 19.07 and the number of distinct categories is 7, indicated that the measurement system is acceptable.

VHMS_1.1	VHMS_1.2	VHMS_2.1	VHMS_2.2
2.83	2.75	2.80	2.85
2.61	2.66	2.60	2.55
2.42	2.48	2.50	2.55
3.03	2.98	3.05	3.00
2.49	2.60	2.65	2.60
2.77	2.82	2.85	2.80
3.25	3.20	3.15	3.20

```
                                    Study Var   %Study Var
Source                 StdDev (SD)   (6 * SD)      (%SV)
Total Gage R&R          0.049044     0.29427       19.07
  Repeatability         0.042088     0.25253       16.36
  Reproducibility       0.025178     0.15107        9.79
    Operator            0.000000     0.00000        0.00
    Operator*Part       0.025178     0.15107        9.79
Part-To-Part            0.252511     1.51507       98.17
Total Variation         0.257230     1.54338      100.00

Number of Distinct Categories = 7
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➤ Gage R&R = 19.07 < 20 dan NDC > 4 (acceptable)

Figure 2 Gauge R&R Operational Stop Time

In addition to determining improvement direction, it is important to know or determine its current position for represented block diagram and to calculate the values of Z-LT, Z-ST, and Z-Shift on the technical diagram control vs. process control.

Sugroup1	Sugroup2	Sugroup3	Sugroup4	Sugroup5	Sugroup6	Sugroup7
2.35	2.36	2.05	1.86	2.08	2.26	1.84
2.40	2.41	2.10	1.91	2.13	2.31	1.89
2.45	2.46	2.15	1.96	2.18	2.36	1.94
2.50	2.51	2.20	2.01	2.23	2.41	1.99
2.55	2.56	2.25	2.06	2.28	2.46	2.04
2.60	2.61	2.30	2.11	2.33	2.51	2.09
2.65	2.66	2.35	2.16	2.38	2.56	2.14
2.70	2.71	2.40	2.21	2.43	2.61	2.19
2.75	2.76	2.45	2.26	2.48	2.66	2.24

Probability Plot of Data

Probability Plot of Data
Normal

Mean 2.314
StDev 0.2407
N 63
AD 0.235
P-Value 0.782

P > 0.05 (normal distribution)
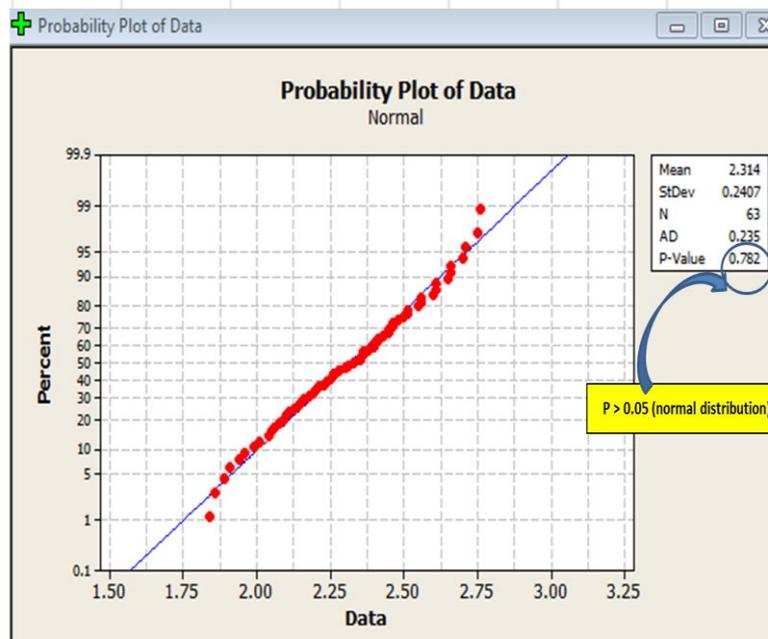
Figure 3 Probability Plot of Data

The results show that the values of Z-ST and Z-Shift are 1.05 and 3.81, respectively; they indicate a lack of process control and lack technical knowledge and allowing for continual improvement stage as shown in Figure 4.
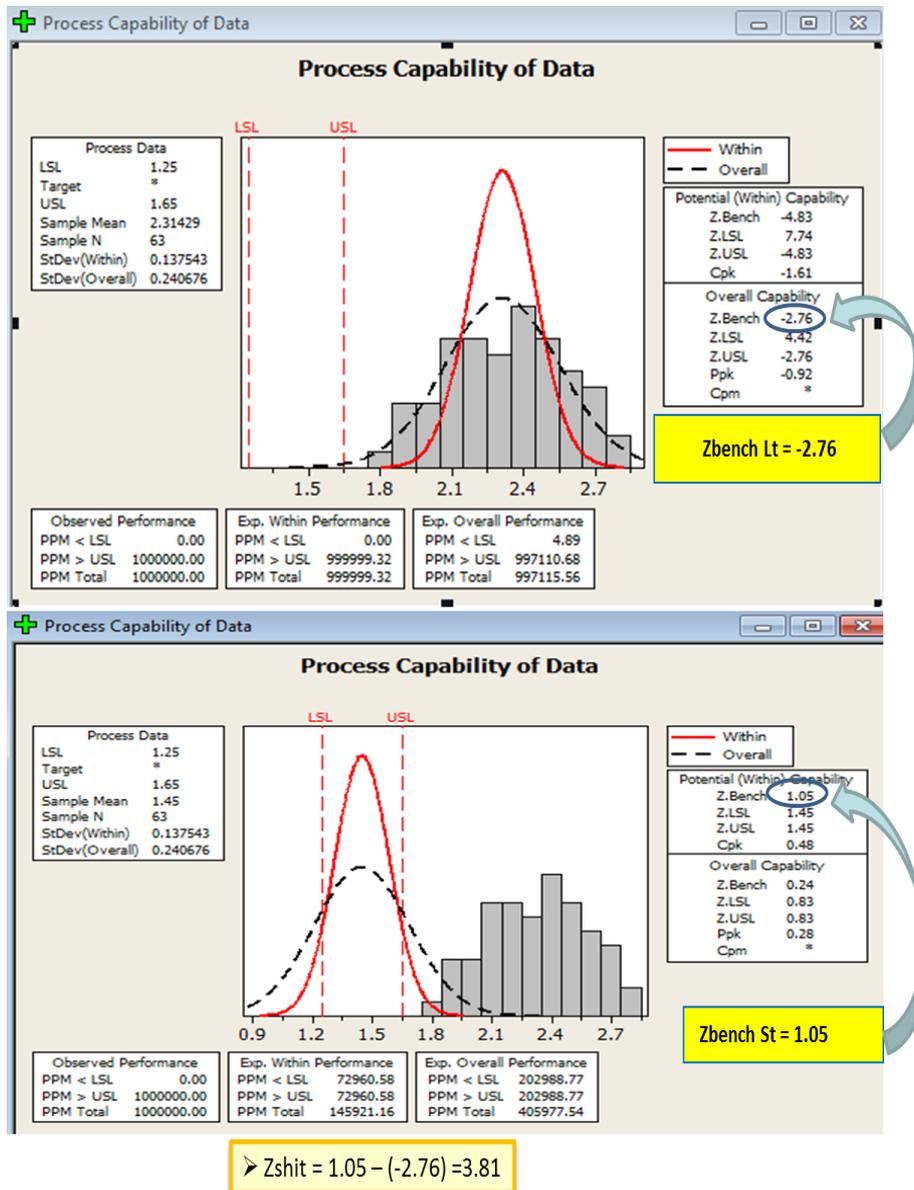
Figure 4 Process Capability before Improvement

Analyze

Measurement results show that the potential factor input [F(x)] as measured this study effect on output (Y) of increases in the operational stop time is the speed for loaded and operational trucks, the number of haulage units, and the skill of the operator. Furthermore, a statistical analysis was conducted to determine the vital few significant factors out of a large potential factors being estimated.

X1: speed vs operational stop time testing

Table 1 Measurement Resultof of *Operational Stop Time*
with Speed 21km/h & 22km/h

Unit	Time	Speed	
		22 km/h	21 km/h
HD465_1	(min.)	2.40	2.15
HD465_2	(min.)	2.30	2.20
HD465_3	(min.)	2.40	2.10
HD465_4	(min.)	2.45	2.20
HD465_5	(min.)	2.35	2.25
HD465_6	(min.)	2.40	2.15

Hypothesis:
Ho = speed not affect operational stop time.
H1 = speed affect operational stop time.

```
Two-sample T for Data

Subscript  N    Mean    StDev   SE Mean
KM_22      6   2.1750   0.0524   0.021
Range 21   6   2.3833   0.0516   0.021


Difference = mu (KM_22) - mu (Range 21)
Estimate for difference:  -0.2083
95% CI for difference:  (-0.2753, -0.1414)
T-Test of difference = 0 (vs not =): T-Value = -6.93  P-Value = 0.000  DF = 10
Both use Pooled StDev = 0.0520
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P-Value < 0.05, "Reject Ho" (speed is vital factor).

X2: number of dump truck vs operational stop time testing

Table 2 Measurement Result of Operational Stop Time with Dump Truck (DT) 6 &7

Unit	Time	Number of DT	
		6	7
HD465_1	(min.)	1.20	2.51
HD465_2	(min.)	1.40	2.55
HD465_3	(min.)	1.30	2.50
HD465_4	(min.)	1.40	2.45
HD465_5	(min.)	1.35	2.55
HD465_6	(min.)	1.50	2.61

Hypothesis:
Ho = number of DT not affect operational stop time.
H1 = number of DT affect operational stop time.

```
SubScript  N    Mean   StDev  SE Mean
X1_6DT     6   1.358   0.102   0.042
X2_7DT     6  2.5283  0.0546   0.022


Difference = mu (X1_6DT) - mu (X2_7DT)
Estimate for difference:  -1.1700
95% CI for difference:  (-1.2817, -1.0583)
T-Test of difference = 0 (vs not =): T-Value = -24.76  P-Value = 0.000  DF = 7
```

P-Value < 0.05, "Reject Ho" (number of dump truck is vital factor)

X3: operator skill vs operational stop time testing

Table 3 Measurement of Operational Stop Time
with Operator 1 and Operator 2

Unit	Time	Operator 1	Operator 2
HD465_1	(min.)	2.51	2.48
HD465_2	(min.)	2.45	2.52
HD465_3	(min.)	2.55	2.50
HD465_4	(min.)	2.40	2.45
HD465_5	(min.)	2.45	2.38
HD465_6	(min.)	2.50	2.40
HD465_7	(min.)	2.50	2.45

Hypothesis:
Ho = operator excavator skill not affect operational stop time.

Probability Plot of Operator1

Probability Plot of Operator2

Two-Sample T-Test and CI: Data, Subscript

```
Two-sample T for Data

Subscript  N    Mean   StDev  SE Mean
Operator1  7  2.4657  0.0568   0.021
Operator2  7  2.4543  0.0509   0.019


Difference = mu (Operator1) - mu (Operator2)
Estimate for difference:  0.0114
95% CI for difference:  (-0.0514, 0.0743)
T-Test of difference = 0 (vs not =): T-Value = 0.40  P-Value = 0.699  DF = 12
Both use Pooled StDev = 0.0540
```

H1 = operator excavator skill affect operational stop time.

P-Value > 0.05, "Accept Ho" (operator excavator skill, not vital factor)

Improvement

The concept of improving results and performance on a continual basis is universally hailed as a great idea. First off, in order to improve continuously, an organization or companies have to improve initially. Based on the test results for the analyze step, it can be seen that there are only two things which might be worth influencing an operational stop time: the speed for loaded and operational truck and the number of haulage units. Under the travel condition and moving at a constant speed, each vehicle is moving at 21 and 22 km/h, the combined of the six and seven vehicles. To obtain the most appropriate combination, improvement steps have been done using the design of experiment (DoE) techniques.

C1	C2	C3	C4	C5	C6	C7
StdOrder	RunOrder	CenterPt	Blocks	Speed	Number of DT	Y
7	1	1	1	22	6	1.70
5	2	1	1	21	6	1.35
6	3	1	1	22	7	2.50
1	4	1	1	21	7	2.25
8	5	1	1	22	6	1.75
2	6	1	1	21	6	1.40
4	7	1	1	22	7	2.45
3	8	1	1	21	7	2.30

Factorial Fit: Y versus Speed, Number of DT

```
* NOTE * Data in the worksheet do not appear to match the units and/or levels
         given for the design.
* NOTE * This design has some botched runs.  It will be analyzed using a
         regression approach.


Estimated Effects and Coefficients for Y (coded units)

Term              Effect    Coef  SE Coef       T      P
Constant                 -30.28  7.01004   -4.32  0.012
Speed               2.50    1.25  0.32596    3.83  0.019
Number of DT        8.10    4.05  1.07529    3.77  0.020
Speed*Jumlah DT    -0.30   -0.15  0.05000   -3.00  0.040


S = 0.0353553    PRESS = 0.02
R-Sq = 99.67%    R-Sq(pred) = 98.69%   R-Sq(adj) = 99.43%


Analysis of Variance for Y (coded units)

Source              DF   Seq SS    Adj SS    Adj MS      F      P
Main Effects         2  1.51250  0.018995  0.009497   7.60  0.043
  Speed              1  0.15125  0.018382  0.018382  14.71  0.019
  Number of DT       1  1.36125  0.017732  0.017732  14.19  0.020
2-Way Interactions   1  0.01125  0.011250  0.011250   9.00  0.040
  Speed*Jumlah DT    1  0.01125  0.011250  0.011250   9.00  0.040
Residual Error       4  0.00500  0.005000  0.001250
  Pure Error         4  0.00500  0.005000  0.001250
Total                7  1.52875
```

As shown by the value of P<5% for Main Effects and 2-Way Interaction, the speed as either a number of vehicles individually or in combination can potentially cause operational stopped time increases. Similarly as seen by the value of R-Sq (adj)>65% which indicates the average speeds and the number of vehicles are contributed for 99.43% of the operational stopped times.
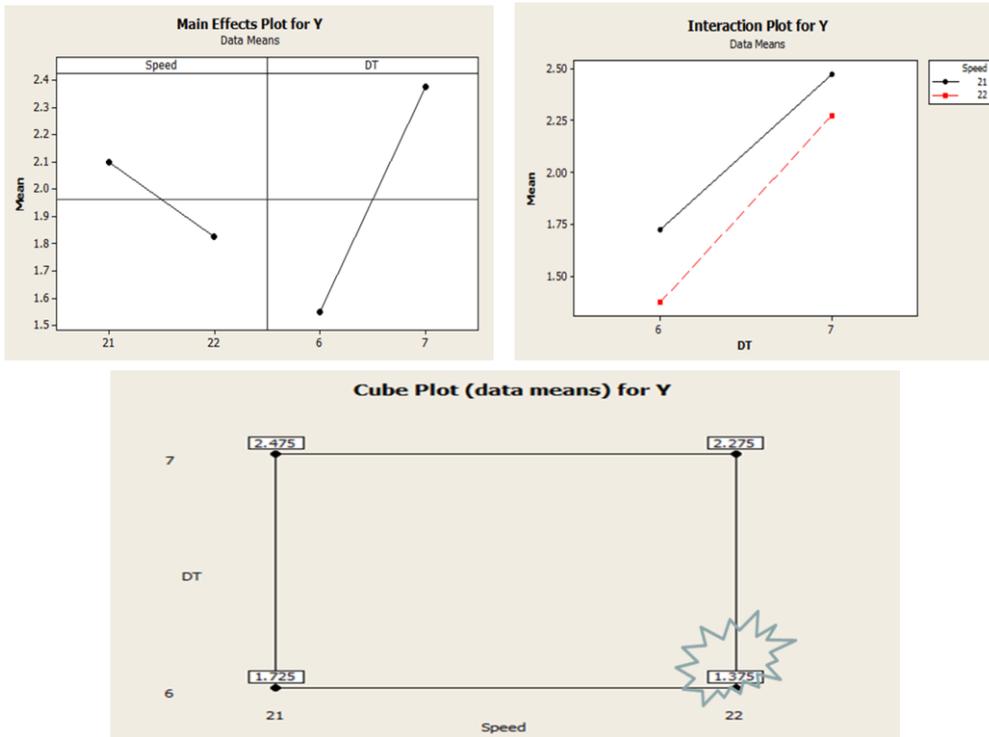
Figure 5 Main Effect Plot DT 6&7 with Speed 21km/h & 22km/h

According to the optimal value, the optimal improvement result can be obtained by only combining a speed of 22 km/h and a number fleet of 6 units. In these combination exercises, the average operational stop time is 1.375 minutes, as shown in Figure 5.

Control

Six Sigma emphasizes the control phase because previous attempts at improving performance repeatedly demonstrated that the whole process is complex and that hard-earned gains slip away if the process is left to itself. A well-designed process exhibits inherent self-control, while a poorly designed process requires frequent external control and adjustment to meet requirements.
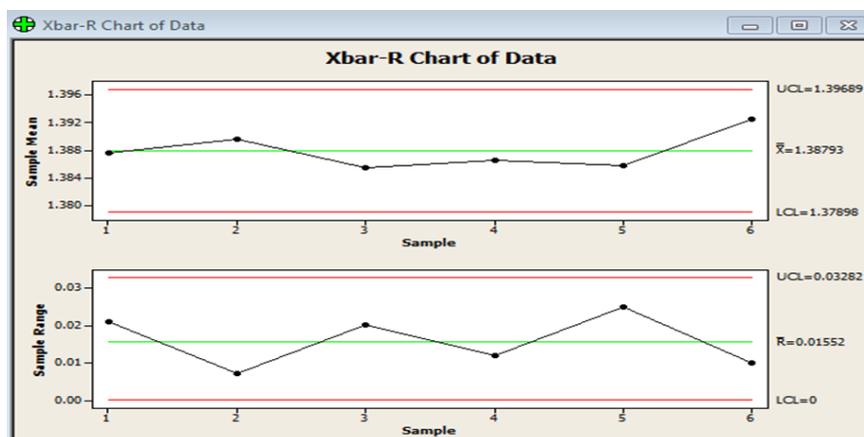
Figure 6 Process Capability Control Diagram

In order to apply the DMAIC tools developed, the organization or companies need to put this information into handbook of the standard of operational stopped time: 1.25 to 1.65 minutes are required for haul lengths of 2,000 meter, with a fleet of 6 dump trucks and a uniform velocity of 22 km/h.

RESULTS AND DISCUSSIONS

The purpose of the Six Sigma process is to identify and contain the vital views variables. In order to undertake hypothesis, a test is needed to express the research hypothesis as a null and alternative hypothesis. The null hypothesis and alternative hypothesis are statements regarding the differences or effects that occur in the population. Sample is used to test which statement (i.e., the null hypothesis or alternative hypothesis) is most likely (although technically, we test the evidence against the null hypothesis). The level of statistical significance is often expressed as the so-called *p*-value.

The cube plot shown in Figure 4 expresses the relationship between average speed, the vehicle fleet size, and operational stop times. For example, an operational stop time at 1.75 minutes requires the average speed of 21 km/jam and a fleet of 6 vehicles. With the figures = 1.375; 2.275; and 2.475 the corresponding initial value would be 22 and 6; 22 and 7; and 21 and 6, respectively. These exercise results suggest that only under a combination of speed of 22 km/h and a fleet size of 6 vehicles yielded the most optimal improvement with an operational stop time around 1.375 minutes.
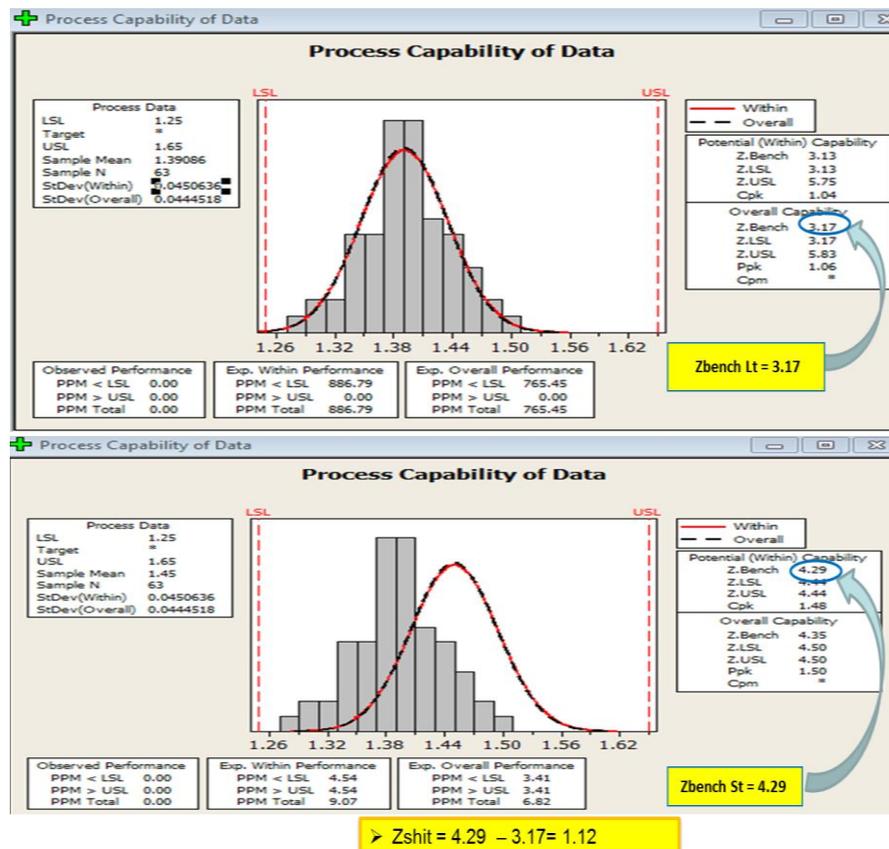
Figure 7 Process Cabality after Improvement

As shown in Figure 7, the initial values of Z_{-ST} and Z-shift are 1.05 and 3.81 (quadrant A), respectively, that has changed by improving steps. The new values of Z_{-ST} and Z-shift are 4.29 and 1.12, respectively, (values of Z_{-ST} - Z_{-LT}) indicate that operational stop time and their related quantity variables have been performed. Furthermore, the process of capability analysis entails comparing the performance of a process against its specifications. We say that a process is capable if, virtually, all of the possible variable values fall within the specification limits. Graphically, we assess process capability by plotting the process specification limits on a four block diagram as shown in Figure 8.
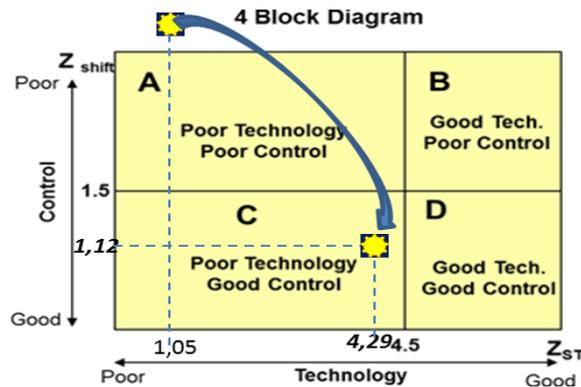
Figure 8 Process Capability Plotting on Four Block Diagram

If a value of capability process is within quadrant A, it means the problems is strongly related to poor technology and control aspects. The capability process that remains in quadrant B means that the technology is appropriate but less controlling. By contrast, an organization or company within quadrant C means that it lacks proper implementation of technologies but has appropriate controls to the user. The ideal one is given by the quadrant D (world class), where the capability process related to the technology implementation and control measures are fully integrated. Six Sigma as a management system can be easily implemented to raise productivity, increase the bottom line, improve quality and the customer experience, and increase financial savings.

CONCLUSIONS

Six Sigma has been successfully implemented to reduce operational stop times of dump truck Hauler HD 465-7 by 51% to average 1.38 from 2.83 minutes previously. This has successfully reduce its expenditure costs from US$ 1.105.300 to US$ 963.000 or provide savings and benefits about US$ 142.300 per month. Corrective action is taken to eliminate the causes of an existing operational stop time to address the problems identified. After trying a pair of possible combination of input variables and saw which combination performs the best, it was found out that a fleet of 6 dump trucks with a uniform velocity of 22 km/h for haul length of 2,000 meters would yielded a range of 1.25 to 1.65 minutes of the operational stop time. In the efforts of improvement, the values of Z_{-ST} and Z-shift have been changed to 4.29 and 1.12 from 1.05 and 3.81, to show that the capability process has become better. It is noted that from the plotting that uses the four block diagram shows the values of Z short term (Z_{-ST}) and Z-shift are ≥4.5 and ≤1.5, indicating the project needs process improvement towards quadrant D, in terms of technology used and control measures. In addition to providing more financial savings, the success of a Six Sigma project can also be seen in the changes grade of values of Z_{-ST} and Z-shift towards quadrant D (appropriate technology and control measures) which is considered under nearly ideal conditions.

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